Spatial Analysis of the Impact of Leachate on Groundwater around Sukosari Open Dumping, Karanganyar, Central Java, Indonesia

ABSTRACT

This study was conducted to determine the impact of leachate pollution from landfills on the quality of well water around them and to map the leachate distribution. A total of eight sample locations were taken for laboratory testing, of the eight samples one was taken at the leachate outlet and the others were taken from wells around the Landfill. Laboratory tests were conducted to analyze the parameters of *Potential Hydrogen* (Ph), *Biological Oxygen Demand* (BOD), *Chemical Oxygen Demand* (COD), *Total Suspended Solid* (TSS), *Mercury* (Hg), *Cadmium* (Cd), *Lead* (Pb), and *Iron* (Fe). The results of the test show that the pH and mercury parameters do not exceed the quality standards, however, other parameters such as BOD, COD, TSS, CD, PB, and FE show values that exceed the quality standards. The standard for drinking water quality is based on the World Health Organization (WHO) and the Regulation of the Minister of Health (PERMENKES) of the Republic of Indonesia No. 02 of 2023 and PP No. 22 of 2021. The data creates a pollution distribution map showing areas with significant contamination levels. This finding indicates a significant influence of activities at the landfill on the quality of the surrounding groundwater. This study highlights the importance of proper leachate management to prevent further pollution. And to provide education to the community, especially those who use wells for consumption purposes, to carry out treatment first before consuming.

Keywords: *Landfill, Leachate, Distribution, Sukosari, Groundwater*

1. INTRODUCTION

The increasing population, industrial activities, and consumerism patterns have resulted in significant solid waste in urban areas [1]. The waste management system in Indonesia consists of the Open Dumping method, the Sanitary Landfill method, and the Controlled Landfill method [2]. Currently, waste management in Indonesia, especially domestic waste, mostly uses the Open Dumping final disposal system [3]. Based on data from the Ministry of Environment and Forestry in 2023, it was recorded that Indonesia produced 17,441,415.28 tons/year and only 66.47% of waste was managed or around 8,805,466.77 tons/year, while 33.53% of waste or around 5,848,304.32 tons/year was not managed.

One of the main problems that arise with the Open Dumping system in a city is continuous waste as a result of rainfall there is an increase in water levels, and the formation of leachate occurs [4]. A series of physical–chemical and biological reactions occur in solid waste, therefore leachate contains a large number of pollutants [5]. Such as organic materials, heavy metals, halogenated hydrocarbon materials, ammonia gas, organic salts, and chlorinated inorganic and vary according to weather conditions, soil conditions, landfill location, landfill age, and the composition of waste generation [6].

Leachate from landfills contains organic materials with high concentrations of *Biological Oxygen Demand* (BOD) ranging from 40,000 to 80,000 mg/L [7]. Among organic materials is a distinct subset known as pollutants [8]. Pollutants comprise a series of heterogeneous chemicals that usually do not affect the environment. If left unchecked, they will cause ecological impacts or impacts on humans [8]. The impact of poor landfill management results in increasingly declining environmental quality [9]. Apart from producing leachate, open dumping landfills also produce CH_4 which, if inhaled every day, will hurt human health [10]. Leachate contains various hazardous chemicals such as heavy metals, organic compounds, ammonia, and pathogenic microorganisms [11]. If leachate is not managed properly it can seep into the ground and contaminate groundwater [12].

The impact of leachate on groundwater is that leachate carries toxic chemical compounds such as lead, mercury, and cadmium [13]. The presence of this compound has the potential to change the pH of groundwater to acidic or alkaline and can increase toxicity so that the water is not suitable for consumption [14]. Leachate also causes an increase in turbidity and color of the water, leachate containing organic materials can cause the water to become cloudy and dark in color [15]. As a place for the growth of pathogenic microorganisms, the organic content of leachate can support the growth of pathogenic microorganisms and become a source of disease if consumed [16]. Leachate causes damage to the aquifer ecosystem, causing a reduction in the diversity of natural microbes that are important for environmental balance [17].

Leachate is also dangerous for humans, the impact of leachate on humans if leachate contaminates the water consumed can cause health problems [18]. Disorders of the nervous system, due to the presence of heavy metals and lead. Causes skin and gastrointestinal diseases due to the presence of pathogenic microorganisms [19]. Leachate also has an impact on kidney and liver damage due to organic and toxic compounds [20].

Several studies have been conducted to determine the distribution of leachate, especially in Indonesia, but using different methods and parameters. The research that has been conducted is still limited in scope and uses three parameters to determine the level of leachate pollution [21]. In addition, other research uses geoelectric methods to determine the distribution of leachate underground [22].

The purpose of this study is to determine the distribution of leachate around the Sukosari Open Dumping Landfill. This was conducted by collecting samples within a 1 km radius of the landfill, including water from community wells and leachate from the landfill's leachate drainage channels. The next stage involved processing the laboratory data to analyze the leachate distribution using ArcGIS software. The creation of the map is expected to be useful for overcoming and creating methods that aim to reduce the spread of leachate. And can provide information to the community about water pollution in community wells.

In accordance with the objectives of the SDGs in point 6.3 regarding improving water quality by 2030, the goals are to Reduce pollution, eliminate waste discharge, minimize the release of hazardous materials and chemicals, Halve the proportion of untreated wastewater, and increase safe recycling and reuse globally.

2. METHODOLOGY

2.1 STUDY AREA

Karanganyar Regency is one of the regencies in Central Java Province, Indonesia with an area of 77,379 Ha (BPS Karanganyar 2024)[23]. The final waste disposal center in Karanganyar Regency is located in Sukosari Village, Jumantono District, which has existed since 1994 [24]. Based on data from the Karanganyar Regency Environmental Service, the Sukosari Landfill accommodates waste from the Jumantono, Jumapolo, Jatipuro, Kebakkramat, Ngargoyoso, Matesih, Karangpandan, Tasikmadu, Karanganyar, Jatiyoso, Mojogedang, and Jenawi Districts (DLH Karanganyar, 2020). The area of the Sukosari Landfill based on the National Waste Management Information System (SIPSN) website is 5.60 Ha, in 2022 the waste entering this Landfill will be 32,850 tons/per year.

The capacity of the Sukosari Landfill has exceeded the limit, but because there is no suitable area to be used as a Landfill and based on the Regency Rencana Tata Ruang Wilayah (RTRW), the Landfill is still being used now [25]. The Sukosari Landfill receives around 150 tons of waste every day [26]. The type of waste in the Sukosari Landfill is 60% organic waste, so the smell in the Landfill is quite pungent [25]. The research location is shown in Figure 1, which also displays the direction of groundwater flow. The direction of groundwater flow was determined through field measurements by measuring the depth of the water table from wells around the landfill.

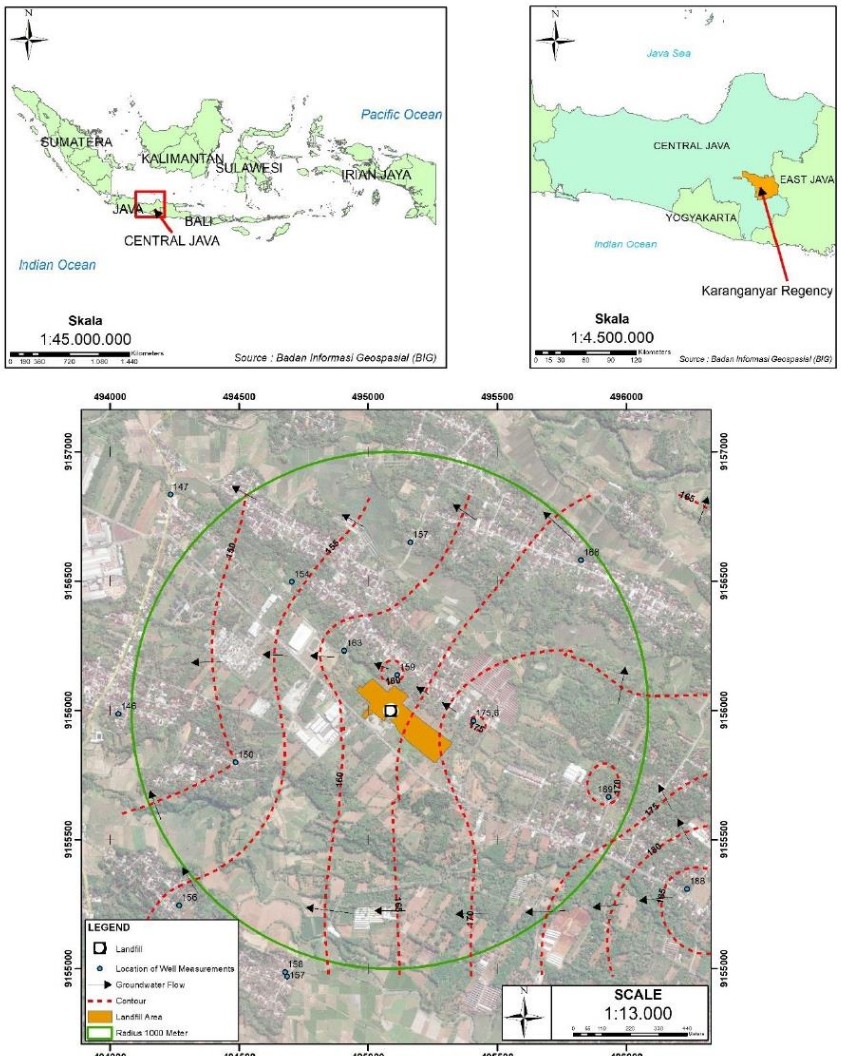

Figure 1. Study Area and Groundwater Flow

2.2 SAMPLING METHOD

Sampling of leachate and groundwater was carried out using a water sampling method based on SNI 6989.58:2008. Sampling was carried out at eight predetermined locations based on the direction of groundwater flow around the Sukosari Landfill. Water sampling is based on the direction of groundwater flow to determine the distribution of leachate [27], and sampling was carried out around the Landfill with a radius of 1 km. Water sampling is prioritized in community wells that use a dug system. The distribution of leachate that seeps through the pores of the soil is very possible so it has the potential to pollute community wells [28].

2.3 DATA PROCESSING

The parameters tested to determine the suitability of water for consumption are pH, BOD, COD, TSS, *Mercury*, *Cadmium*, *Lead* (Pb), and *Iron* (Fe). The determination of parameters for water quality testing is based on the leachate parameters outlined in the Regulation of the Minister of Environment and Forestry No. 07 of 2016. The results of laboratory test data with 8 (eight) parameters will be adjusted to the standard standards according to the World Health Organization (WHO) and the Regulation of the Minister of Health of the Republic of Indonesia (PERMENKES) RI No. 02 of 2023 and PP No. 22 of 2021 for standard parameters for the quality of drinking water. After the data from the Laboratory is obtained and adjusted to the quality standards, the next step is to make a map. The map that is made is based on the data on the suitability of the quality standards to determine the distribution of leachate pollution.

Parameter testing is based on applicable standards, Ph testing is adjusted to SNI 6989.11:2019. BOD content testing is by SNI 6989.72:2009, COD testing is adjusted to SNI 6989.2:2019. Water quality testing to determine TSS content is adjusted to SNI 6989.3:2019, and Mercury content testing is adjusted to SNI 6989.78:2019. Cadmium (Cd) content testing is adjusted to SNI 06.6989.38:2005, for Lead (Pb) content testing in sample water is adjusted to SNI 6989-84:2019. Next, check the iron (Fe) content using SNI 6989-84:2019.

The results of laboratory data and adjustments to drinking water quality standards will be interpreted into a map. The stages of map creation are carried out by inserting data based on the results at each sample location. After that, it is entered into the ArcGIS software to be processed into a map by performing Data Interpolation, then *Inverse Distance Weighted* (IDW) is carried out, then adjustments are made to the symbology so that the map can be easily understood by the reader.

3. RESULTS AND DISSCUSSION

The results of laboratory tests on the distribution of leachate around the Sukosari landfill indicate that leachate is polluting community wells. However, the pollution is not too significant when viewed in each parameter. The results of laboratory tests are based on the classification of the suitability of well water for consumption from WHO, PERMENKES, and PP No. 22 of 2021. The presentation of pollution distribution data using a map is shown as follows.

3.1 INDICATORS POTENTIAL HYDROGEN (PH)

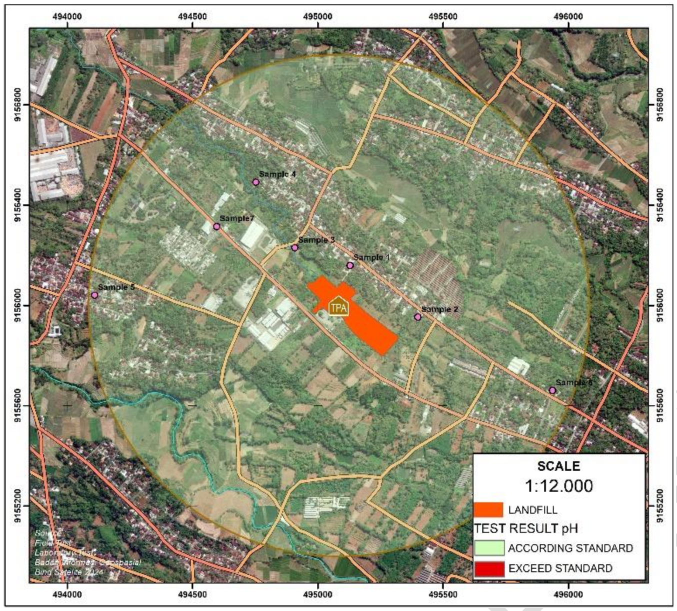

Figure 2. pH Distribution

Figure 1 shows the distribution of leachate pollution that affects the pH of the wells. Based on the results of laboratory analysis, the pH levels around the Sukosari Landfill are still by the quality standards for drinking water. The standard pH quality of drinking water based on WHO standards is 6.5 - 8.5, while the standard based on PERMENKES and PP No. 22 of 2021 is 6.5 - 8.5. Based on the results of laboratory tests for the pH content around the Sukosari Landfill, it ranges from 6.92 - 7.29.

3.2 INDICATORS BIOLOGICAL OXYGEN DEMAND (BOD)

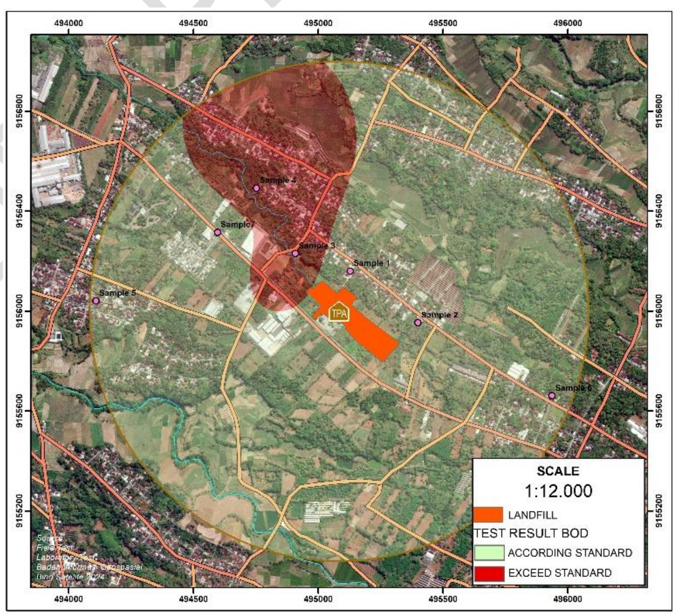

Figure 3. BOD Distribution

The distribution of *Biological Oxygen Demand* (BOD) around the Sukosari Landfill is based on data from field sampling and laboratory tests, the distribution of BOD is towards the West side of the Landfill. From the results of laboratory tests for water quality standards, they are adjusted to WHO and PERMENKES standards as well as PP No. 22 of 2021. Data from laboratory test results show that samples 3 and 4 exceed the standard with BOD content of 5 and 4.9 mg/L exceeding the quality standard, which is below 2 mg/L. Based on Figure 3, the distribution of BOD is directed towards the western side of the landfill. This is influenced by the direction of groundwater flow and the waste composition, which predominantly consists of organic matter.

3.3 INDICATORS CHEMICAL OXYGEN DEMAND (COD)

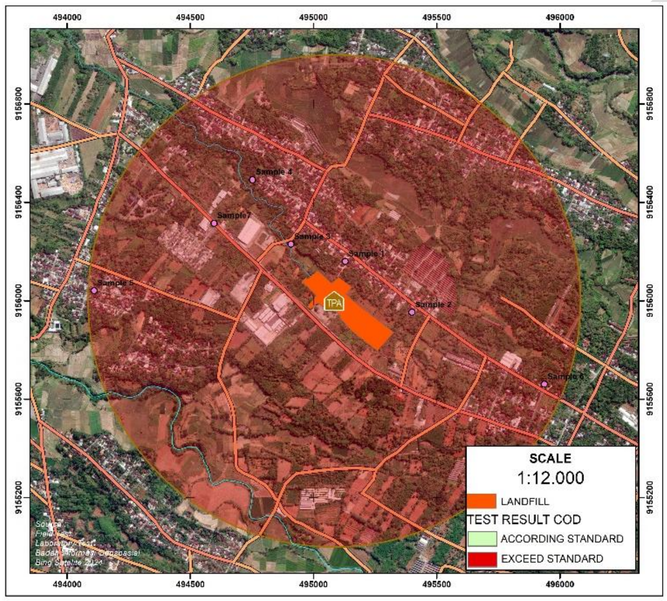

Figure 4. COD Distribution

The distribution of *Chemical Oxygen Demand* (COD) based on the samples taken did not comply with the quality standards based on the PERMENKES and PP No. 22 of 2021 standards. Based on the quality standards of the Minister of Health Regulation and Government Regulation No. 22 of 2021 for drinking water standards for COD content, namely below 2.49 mg/L. Meanwhile, for the laboratory results, all samples taken exceeded the quality standards, while the highest level was in sample 4 with a COD content of 44.22 mg/L. Based on the eight sampling locations for the COD parameter, all exceeded the standard, as shown in Figure 4.

3.4 INDICATORS TOTAL SUSPENDED SOLID (TSS)

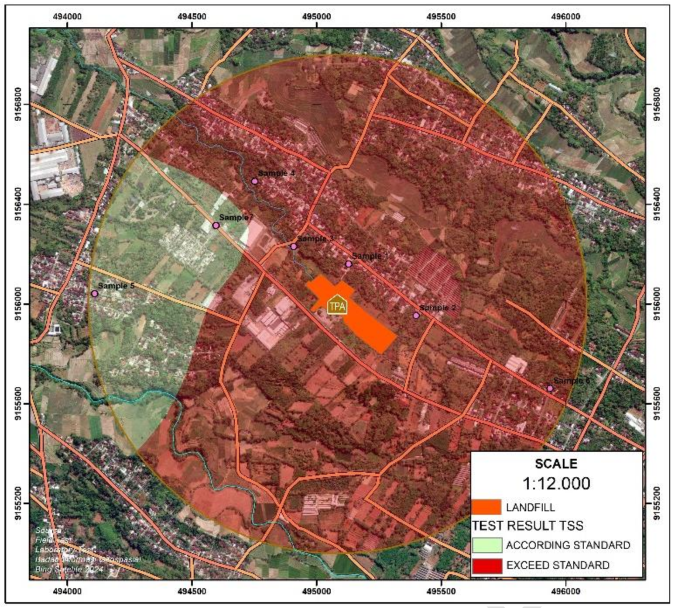

Figure 5. TSS Distribution

Based on the results of field sampling and laboratory tests for the distribution of *Total Suspended Solid* (TSS) quality from the impact of the uncontrolled distribution of landfill leachate, the water sources of the surrounding community have been polluted. The distribution of pollution for the TSS parameter around the Sukosari landfill has caused most of the sampled areas to experience contamination. As shown in Figure 5, the majority of the study locations do not meet the quality standards set by the PERMENKES No. 22 of 2021. Of the eight (8) samples taken, 6 of them exceeded the quality standard, for the TSS quality standard, which was below 2.5 mg/L. Meanwhile, 2 of them were below the quality standard from the laboratory results for the most polluted location, which was in sample 3 with a TSS content of 16 mg/L.

3.5 INDICATORS MERCURY (Hg)

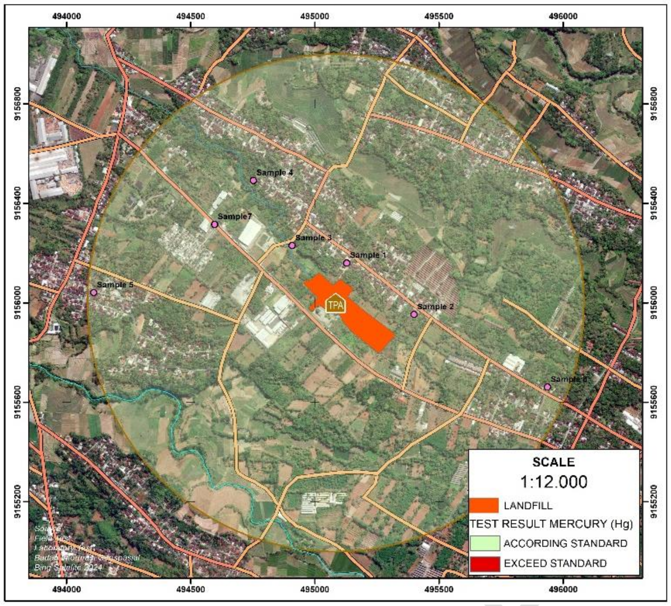

Figure 6. Hg Distribution

Based on field sampling and laboratory testing of *Mercury* (Hg) parameters in wells around the Sukosari Landfill. It was found that mercury pollution from the impact of leachate distribution did not pollute the water sources of the surrounding community. One of the factors is that the waste dumped at Sukosari Landfill is mostly organic [25]. And there is little waste containing mercury so mercury pollution around the Landfill is quite low. As shown in Figure 6, the eight sampling locations did not experience any contamination.

3.6 INDICATORS KADMIUM (CD)

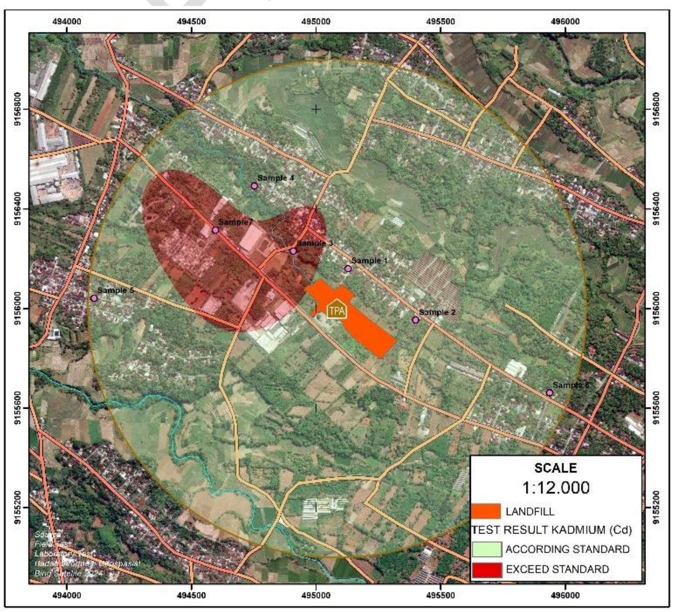

Figure 7. CD Distribution

Distribution of *Cadmium* (Cd) pollution around the Sukosari Landfill from leachate seepage, based on laboratory results. The distribution of Cd is known to flow towards the western side of the landfill, as shown in Figure 7. Based on laboratory results for cadmium content in sample wells 3 and 4, the CD content is around 0.007 and 0.01, while the standard quality according to WHO and PERMENKES and PP No. 22 of 2021 is below 0.001 mg/L.

3.7 INDICATORS LEAD (PB)

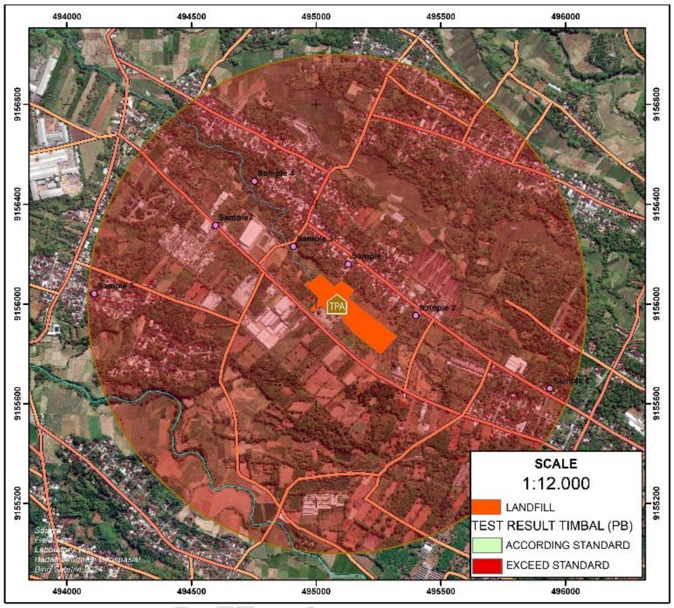

Figure 8. Pb Distribution

Distribution of *Lead* (Pb) around the Sukosari Landfill based on laboratory test results shows that for water quality from the *lead* (Pb) parameter, all samples taken around the Landfill exceed the quality standard for lead (Pb) as shown in Figure 8. The highest value at the polluted location was in sample 5 with a lead content value of 0.227 mg/L. Based on the quality standards according to WHO and PERMENKES and PP No. 22 of 2021 for lead quality standards below 0.01 mg/L. The impact of lead on humans can induce oxidative stress with excessive production of free radicals, and cause damage to cell membranes, through lipid peroxidation [29].

3.8 INDICATORS IRON (FE)

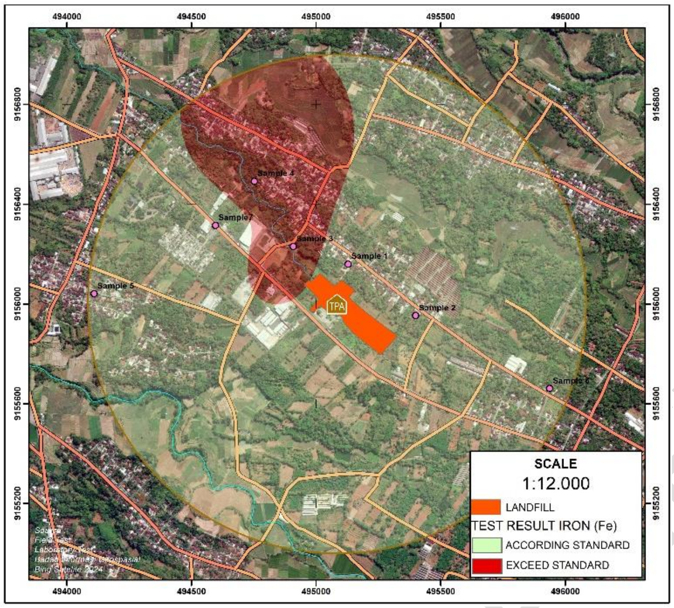

Figure 2. Fe Distribution

Distribution of leachate from Sukosari Landfill which pollutes community water sources based on field sampling and laboratory testing for *Iron* (Fe) parameters. The distribution is directed towards the western side of the landfill, as shown in Figure 9. One of the influencing factors is the presence of irrigation channels and the groundwater flow direction towards the west, which significantly impacts the spread of leachate on the western side. Based on laboratory results, the iron (Fe) content to the west of the landfill is around 0.1 to 0.88 mg/L. Meanwhile, the quality standard for iron (Fe) content in water according to PERMENKES and PP No. 22 of 2021 is below 0.029 mg/L.

4. CONCLUSION

Based on the results of laboratory tests and mapping of the distribution of leachate around the Sukosari Landfill. Within a radius of 1 km from the Landfill location, all well water samples taken were not suitable for consumption based on eight (8) parameters, namely Ph, BOD, COD, TSS, Hg, Cd, Pb, and Fe. Based on the eight parameters for the pH and Mercury parameters, are by the quality standards, but for the COD and Lead parameters, the entire sample exceeds the quality standards, so if the water is still consumed without proper processing, it will trigger negative impacts on health. Results of mapping for the distribution of leachate. Areas prone to pollution are to the west of the landfill because the direction of groundwater flow is to the west and there is a flow of leachate to the west so the western side of the landfill has great potential for leachate pollution.

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1. The author used Google Translate to translate the text.

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3.

REFERENCES

[1] R. Bakhshoodeh *et al.*, "Constructed wetlands for landfill leachate treatment: A review," *Ecol. Eng.*, vol. 146, no. December 2019, 2020, doi: 10.1016/j.ecoleng.2020.105725.

[2] D. Andriani and T. D. Atmaja, "The potentials of landfill gas production: a review on municipal solid waste management in Indonesia," *J. Mater. Cycles Waste Manag.*, vol. 21, no. 6, pp. 1572–1586, 2019, doi: 10.1007/s10163-019-00895-5.

[3] G. A. Kristanto and W. Koven, "Estimating greenhouse gas emissions from municipal solid waste management in Depok, Indonesia," *City Environ. Interact.*, vol. 4, no. 2019, p. 100027, 2019, doi: 10.1016/j.cacint.2020.100027.

[4] A. Siddiqua, J. N. Hahladakis, and W. A. K. A. Al-Attiya, "An overview of the environmental pollution and health effects associated with waste landfilling and open dumping," *Environ. Sci. Pollut. Res.*, vol. 29, no. 39, pp. 58514–58536, 2022, doi: 10.1007/s11356-022-21578-z.

[5] S. Ma *et al.*, "Leachate from municipal solid waste landfills in a global perspective: Characteristics, influential factors and environmental risks," *J. Clean. Prod.*, vol. 333, no. December 2021, p. 130234, 2022, doi: 10.1016/j.jclepro.2021.130234.

[6] Z. T. Khanzada and S. Övez, "Microalgae as a sustainable biological system for improving leachate quality," *Energy*, vol. 140, pp. 757–765, 2017, doi: 10.1016/j.energy.2017.08.112.

[7] Z. Liu, Y. Dang, C. Li, and D. Sun, "Inhibitory effect of high NH4+-N concentration on anaerobic biotreatment of fresh leachate from a municipal solid waste incineration plant," *Waste Manag.*, vol. 43, pp. 188–195, 2015, doi: 10.1016/j.wasman.2015.06.031.

[8] X. Tong *et al.*, "Source, fate, transport and modelling of selected emerging contaminants in the aquatic environment: Current status and future perspectives," *Water Res.*, vol. 217, no. February, p. 118418, 2022, doi: 10.1016/j.watres.2022.118418.

[9] S. Nanda and F. Berruti, "Municipal solid waste management and landfilling technologies: a review," *Environ. Chem. Lett.*, vol. 19, no. 2, pp. 1433–1456, 2021, doi: 10.1007/s10311-020-01100-y.

[10] A. Ghosh, S. Kumar, and J. Das, “Impact of leachate and landfill gas on the ecosystem and health: Research trends and the way forward towards sustainability,” *J. Environ. Manage.*, vol. 336, no. December 2022, p. 117708, 2023, doi: 10.1016/j.jenvman.2023.117708.
[11] H. I. Abdel-Shafy, A. M. Ibrahim, A. M. Al-Sulaiman, and R. A. Okasha, “Landfill leachate: Sources, nature, organic composition, and treatment: An environmental overview,” *Ain Shams Eng. J.*, vol. 15, no. 1, p. 102293, 2024, doi: 10.1016/j.asej.2023.102293.
[12] Ayoola Nike Daniel, Ike Kenneth Ekeleme, Chinemerem Martin Onuigbo, Victor Okezie Ikpeazu, and Smart Obumneme Obiekezie, “Review on effect of dumpsite leachate to the environmental and public health implication,” *GSC Adv. Res. Rev.*, vol. 7, no. 2, pp. 051–060, 2021, doi: 10.30574/gscarr.2021.7.2.0097.
[13] N. Anand and S. G. Palani, “A comprehensive investigation of toxicity and pollution potential of municipal solid waste landfill leachate,” *Sci. Total Environ.*, vol. 838, no. February, p. 155891, 2022, doi: 10.1016/j.scitotenv.2022.155891.
[14] N. Akhtar, M. I. Syakir Ishak, S. A. Bhawani, and K. Umar, “Various natural and anthropogenic factors responsible for water quality degradation: A review,” *Water (Switzerland)*, vol. 13, no. 19, 2021, doi: 10.3390/w13192660.
[15] A. Ibrahim and A. Z. Yaser, “Colour removal from biologically treated landfill leachate with tannin-based coagulant,” *J. Environ. Chem. Eng.*, vol. 7, no. 6, p. 103483, 2019, doi: 10.1016/j.jece.2019.103483.
[16] U. Anand *et al.*, “SARS-CoV-2 and other pathogens in municipal wastewater, landfill leachate, and solid waste: A review about virus surveillance, infectivity, and inactivation,” *Environ. Res.*, vol. 203, no. June 2021, p. 111839, 2022, doi: 10.1016/j.envres.2021.111839.
[17] B. Tan *et al.*, “Review on recent progress of bioremediation strategies in Landfill leachate - A green approach,” *J. Water Process Eng.*, vol. 50, no. August, p. 103229, 2022, doi: 10.1016/j.jwpe.2022.103229.
[18] F. Parvin and S. M. Tareq, “Impact of landfill leachate contamination on surface and groundwater of Bangladesh: a systematic review and possible public health risks assessment,” *Appl. Water Sci.*, vol. 11, no. 6, pp. 1–17, 2021, doi: 10.1007/s13201-021-01431-3.
[19] T. D. Olaolu, “Pollution Indicators and Pathogenic Microorganisms in Wastewater Treatment: Implication on Receiving Water Bodies,” *Int. J. Environ. Prot. Policy*, vol. 2, no. 6, p. 205, 2014, doi: 10.11648/j.ijepp.20140206.12.
[20] C. Khalil, C. Al Hageh, S. Korfali, and R. S. Khnayzer, “Municipal leachates health risks: Chemical and cytotoxicity assessment from regulated and unregulated municipal dumpsites in Lebanon,” *Chemosphere*, vol. 208, pp. 1–13, 2018, doi: 10.1016/j.chemosphere.2018.05.151.
[21] Y. Pratiwi, R. Mardiyan, and P. D. Sukmawati, “Analisis Sebaran Air Lindi Terhadap Kualitas Air Sumur Di Sekitar TPA Sukosari, Karanganyar,” *J. Serambi Eng.*, vol. 7, no. 4, pp. 4084–4094, 2022, doi: 10.32672/jse.v7i4.4513.
[22] F. Ramadhan, F. Prasasti D.R, F. Firizqy, and T. Nugroho Adji, “Pendugaan Distribusi Air Lindi dengan Geolistrik Metode ERT di TPA Piyungan, Bantul, DIY,” *Maj. Geogr. Indones.*, vol. 33, no. 1, p. 1, 2019, doi: 10.22146/mgi.38813.
[23] B. Wahyuningtyas, K. Kusnandar, and S. H. Purnomo, “The Efficiency of Garlic Supply Chain Actors Measured using Data Envelopment Analysis (DEA) Method in Karanganyar, Indonesia,” *Caraka Tani J. Sustain. Agric.*, vol. 35, no. 2, p. 168, 2020, doi: 10.20961/carakatani.v35i2.33114.
[24] I. F. Wibowo, “Prediksi Kebutuhan Daya Tampung TPA Sukosari Jumantono Karanganyar Pada Tahun 2016,” *Univ. Sebel. Maret*, 2011.
[25] R. Fachrurozi, I. W. Widiarti, and R. D. Asrifah, “Evaluasi Tempat Pemrosesan Akhir (TPA) Sampah Sukosari Berdasarkan Indeks Risiko Lingkungan di Desa Sukosari, Kecamatan Jumantono Kabupaten Karanganyar Provinsi Jawa Tengah,” *Pros. Semin. Nas. Tek. Lingkung. Kebumian SATU BUMI*, vol. 4, no. 1, pp. 203–211, 2023, doi: 10.31315/psb.v4i1.8893.
[26] A. Achmad and F. D. Cahyo, “… Pemerintah Daerah Kabupaten Karanganyar Dalam Penyelenggaraan Pengelolaan Sampah Untuk Mendukung Pembangunan …,” *Res Publica*, vol. 1, no. 3, pp. 69–84, 2017, [Online]. Available:

https://jurnal.uns.ac.id/respublica/article/view/46907
[27] F. Chidichimo, M. De Biase, and S. Straface, “Groundwater pollution assessment in landfill areas: Is it only about the leachate?,” *Waste Manag.*, vol. 102, pp. 655–666, 2020, doi: 10.1016/j.wasman.2019.11.038.
[28] J. O. Alao, “The Factors Influencing the Landfill Leachate Plume Contaminants in Soils, Surface and Groundwater and Associated Health Risks : A Geophysical and Geochemical View,” vol. 1, no. 1, pp. 20–43, 2024.
[29] A. Kurabi, K. Pak, A. F. Ryan, and S. I. Wasserman, “Innate Immunity: Orchestrating Inflammation and Resolution of Otitis Media,” *Curr. Allergy Asthma Rep.*, vol. 16, no. 1, pp. 1–9, 2016, doi: 10.1007/s11882-015-0585-2.